# Selection of W-Pair-Production in DELPHI with

# Feed-Forward NEURAL NETWORKS

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- Determination of Systematic Errors
- Summary

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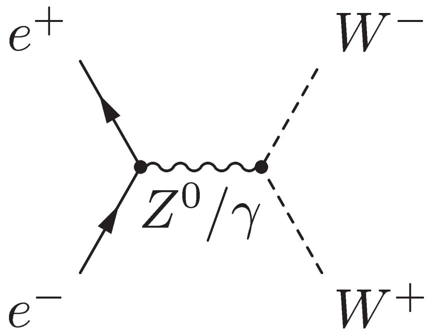
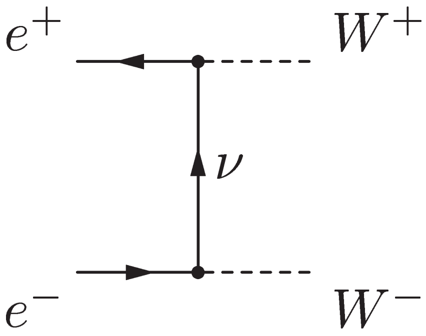
# Introduction




- W-pair-production $e^+e^- \to W^+W^-$ at LEP (CERN) at center-of-mass energies 161 - 208 GeV

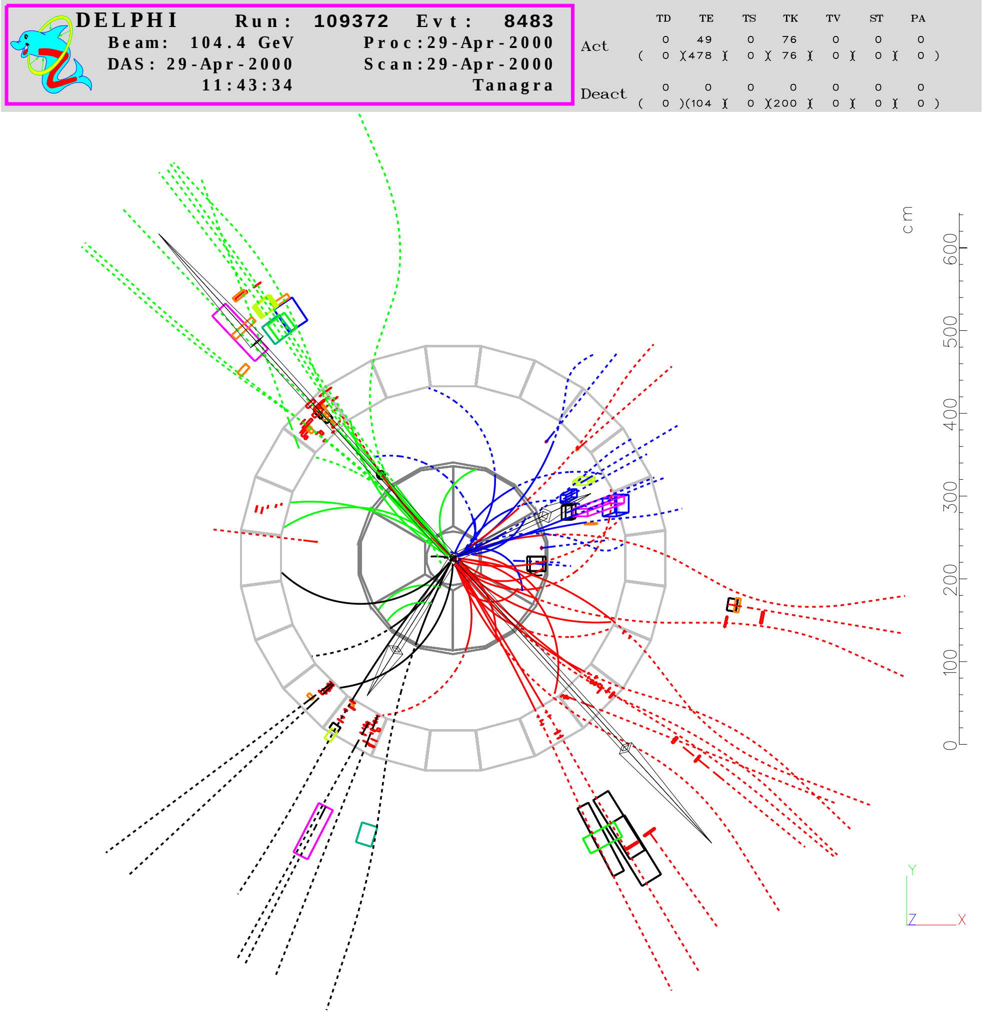
- decay channels:

| | | | |
|---|---|---|---|
| hadronic | : | $W^+W^- \to q\bar{q}q\bar{q}$ | $(45.9\%)$ |
| semileptonic | : | $W^+W^- \to q\bar{q}l\nu$ | $(43.7\%)$ |
| leptonic | : | $W^+W^- \to l\nu l\nu$ | $(10.4\%)$ |

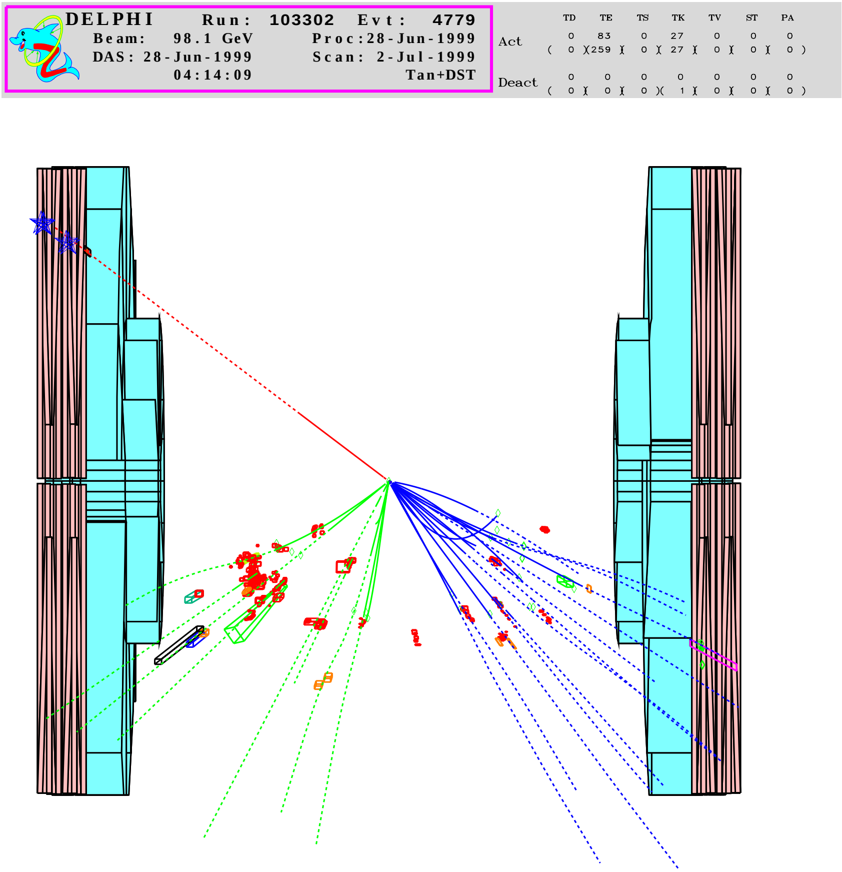
- measurements of production cross sections, W-mass and width as well as branching ratios

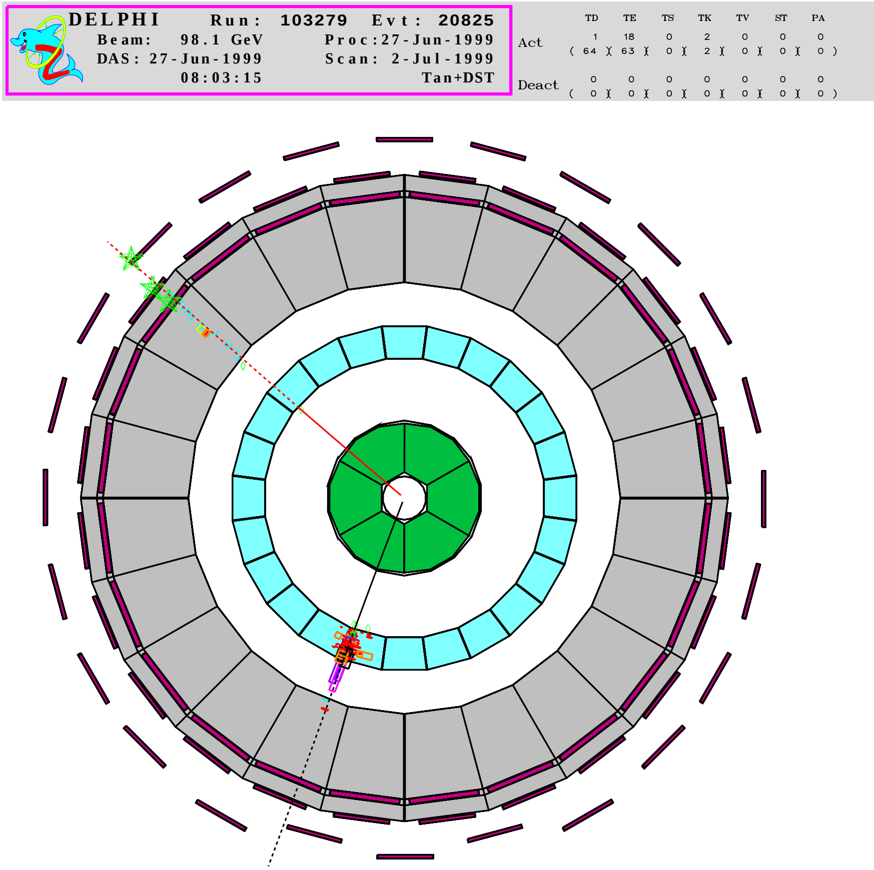
- tests of Standard Model predictions and cross checks with earlier electroweak measurements possible

# Hadronic WW-Candidate



# Semileptonic and Leptonic WW-Candidate



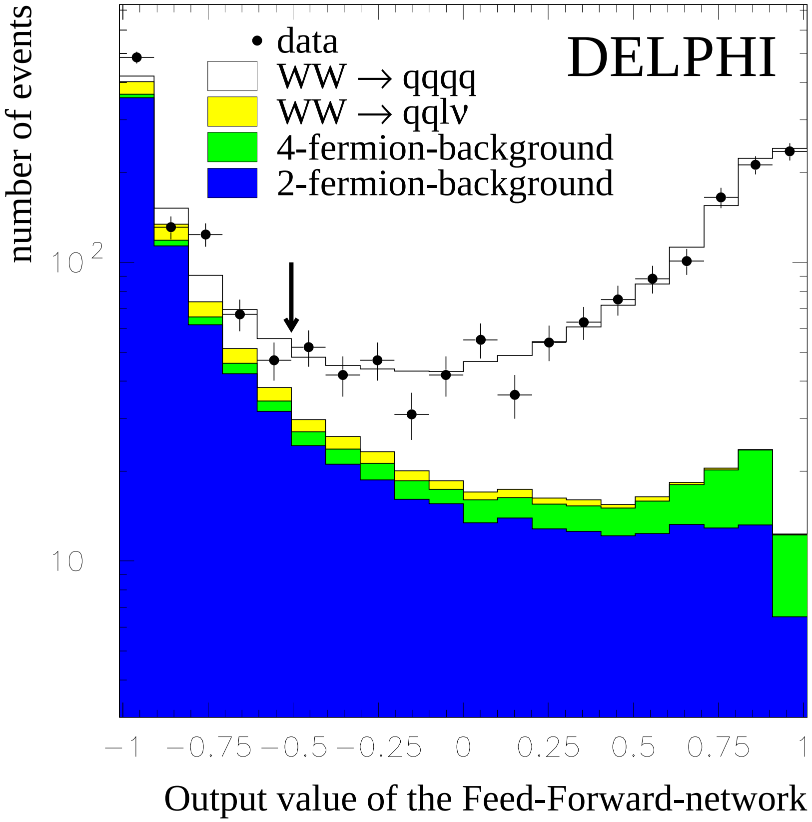
# Hadronic Analysis at 189 GeV

- signal : $e^+e^- \to W^+W^- \to q\bar{q}q\bar{q}$
  $\Rightarrow$ 4-jet event topology with similar quark jets:
  - small differences in jet energies
  - big jet angles
  - high total jet multiplicity
- dominating background : $e^+e^- \to Z^0/\gamma^\star \to q\bar{q}(g)$
  - cross section higher by factor 13
  - initial state photon radiation (Z-returns)
  - 4-jet events with two gluon jets or from a gluon decay
- background : $e^+e^- \to Z^0Z^0 \to q\bar{q}q\bar{q}$
  - same topology like signal and very similar
    $\Rightarrow$ hardly to reject

# Neural Network vs. Linear Cuts

- conventional analysis based on linear cuts
  - effective center-of-mass energy $\sqrt{s'}$
  - number of jets $n_{jet}$
  - total jet multiplicity $N_{all}^{jet}$
  - $D = \frac{E_{min}^{jet} \cdot \Theta_{min}^{jet}}{E_{max}^{jet} \cdot (E_{max}^{jet} - E_{min}^{jet})}$
- feed-forward network with standard backpropagation algorithm
  - loose preselection against non-4-jet-events and Z-returns
  - 13 jet- or event-variables as input nodes:
    $\sqrt{s'}$ , $\Theta_{min}^{jet}$ , $N_{all}^{jet}$, $d_{join}(4 \to 3)$, $E_{max}^{jet} - E_{min}^{jet}$, $b_{min}$, $\sum_{i=1}^{7} |\vec{p}_i^3|$,
    probability from constrained fit, rapidity, sphericity, thrust, H3, H4
  - architecture 13 - 7 - 1
  - 3500 training MC-events from signal and QCD-background
  - test with additional ZZ MC-training sample and 3 output nodes
    $\Rightarrow$ more CPU time , result not improved

# Selection Results at 189 GeV




| | | NN | cuts |
|---|---|---|---|
| signal efficiency | [%] | 88.74 | 85.58 |
| remaining bg | [$pb$] | 1.886 | 2.228 |
| selection purity | [%] | 77.84 | 74.14 |
| eff $\times$ pur | [%] | 69.08 | 63.45 |
| selected events | | 1298 | 1342 |

$\Rightarrow$ clear improvement in selection quality, similar at all other LEP-energies

$\Rightarrow$ NN chosen for DELPHI cross section analysis

# Systematic Studies I

systematic errors of signal efficiency and remaining background necessary basis for error of cross section

## studies of network stability:

- test of different network architectures
- use of different numbers of training events and of different training samples
- variation of network parameter $\eta$ (learning rate, $0.0025^{+0.015}_{-0.0015}$) and $\alpha$ (momentum term, $0.56 \pm 0.3$)

$\Rightarrow$ all results compatible within statistical uncertainties

$\Rightarrow$ no contribution to systematic errors assumed

# Systematic Studies II

## systematic studies using NN as mathematical function (black box)

fixed training, always the same cut

- comparison of MC generators with different hadronisation models and different MC parameter settings

- data-MC-agreement using the technique of mixed Lorentz-boosted $Z^0$

- smearing of input variables taking detector resolution into account

- influence of final state interactions on signal efficiency (Bose-Einstein correlation and colour reconnection)

# Final Result

- systematic effect on efficiency and background for each method
- combination of different systematics taking into account correlations between methods
- determination of cross section from binned maximum likelihood fit to output distribution taking into account the expected background

final result for NN analysis:

$$\boxed{\sigma_{W^+W^-\to q\bar{q}q\bar{q}} = 7.36 \pm 0.26\,(stat) \pm 0.10\,(syst)\,pb}$$

as comparison result for linear cuts:

$$\sigma_{W^+W^-\to q\bar{q}q\bar{q}} = 7.56 \pm 0.28\,(stat)\,pb$$

(systematic error expected to be compatible to NN analysis)

# Summary

- application of feed-forward neural network in direct selection of hadronic WW-candidates

- significant improvement in selection quality compared to standard analysis

  $\Rightarrow$ DELPHI cross section analysis based on this selection procedure

- complete determination of systematic error for publication
  - tests of network stability only as cross checks
  - based on ideas for linear cut analyses
  - neural network as mathamatical function